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REVIEW

Vitis sp., Vitaceae and viticulture in the Indus Civilization, South Asia ca. 3200–1500 BC: a critical review

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Abstract

Grape (*Vitis vinifera* L. ssp. *vinifera*) has been identified as part of the Indus Civilization crop assemblage. As a non-native crop, with a wild ancestor that does not grow in the region, its presence in northern South Asia ca. 3200–1300 BC has thus been used to argue variously as evidence for crop diffusion, long distance trade, and the adoption of foreign agricultural strategies and foodways. Grape identification, particularly between wild and domesticated species, is complex. In this article the challenges of identifying 'grape' in South Asian antiquity are explored. The overreliance on length, breadth and thickness measurements, with limited description and a lack of standardisation are considered. Furthermore, an examination of the local flora demonstrates that there are multiple Vitaceae genera being possible 'grape' contenders in the region. Identification criteria for local Vitaceae need to be better developed to more understand the role of Indus grapes in order for the complicated social interpretations of 'what grapes means in the Indus' to be maintained.

Keywords Asia · Indus Civilization · South Asia · Vitaceae · Taxonomy · Identification · Grapes

Introduction

Today, grape (*Vitis vinifera* L.) is one of the economically most important fruit species in the world. In 2017, grapes were harvested from ca. 7 million ha of land which produced 10,716 kg/ha (http://www.fao.org/faostat/en/#data/QC). In antiquity, records of human use of domesticated grapes from archaeological remains go back to the Early Bronze Age in the Near East (see Miller 2008 for summary), with residue analysis pushing wine use back to the Neolithic in the Near East (McGovern et al. 1996; McGovern 2003) and Greece (Pagnoux et al. 2021). Archaeobotanical remains consisting of grape pressing is supporting it (Garnier and Valamoti 2016). Evidence for wild grape exploitation can be found even as far back as Palaeolithic deposits (Hansen and Renfrew 1978; Vaquer et al. 1986; Marinval 1997; Martinoli 2004; Weiss et al. 2004).

In other regions however, early identifications of domesticated grape are often difficult and controversial, and this is the case in the Indus Civilization. By 2500 BC this extensive Old World Bronze Age civilization had spread across a vast area of north western South Asia in what is now Pakistan and northwest India (Fig. 1, Table 1). People's use of plants in this civilization is a topic of intense debate (e.g. Vishnu-Mittre 1974,1982; Weber, 1991; Fuller and Madella 2002; Weber et al. 2011a; Petrie et al. 2016; Petrie and Bates 2017; Bates 2019a, b). However, our understanding of the use of plants by Indus peoples derives from a patchy archaeobotanical record that has likely been biased towards the remains of cereals and pulses. Recent papers have questioned how we can use our data to explore the less commonly discussed crops that Indus peoples exploited such as fruits, oilseeds and spices (e.g. Kashyap and Weber 2010; Weber et al. 2011b; Bates 2019a, b). These 'missing' components of Indus food habits are a critical part of understanding Indus plant exploitation and foodways, but the inclusion of these remains in discussions requires rigorous identification and interpretation (Bates 2019a, b).

Grape in particular is one such fruit that requires more careful exploration of how it is incorporated in our models of Indus food habits. The Indus Civilization sits outside the zone for the wild grape ancestor of modern domesticated

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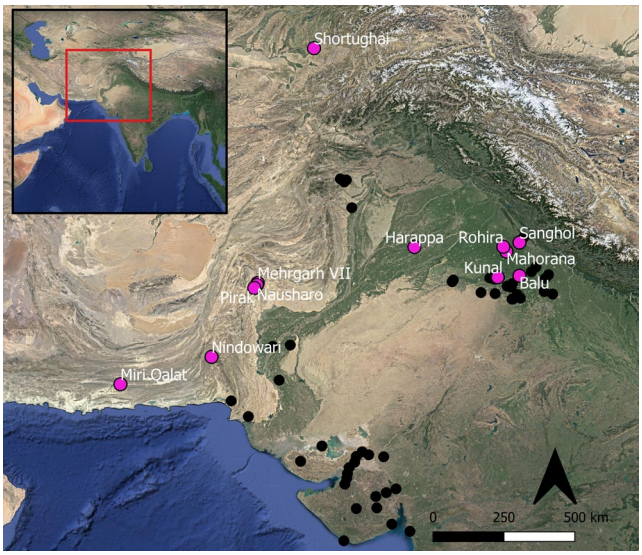

Fig. 1 Map of the Indus Civilization sites with archaeobotanical remains (based on Bates 2019b); labelled sites are those with reported 'grape' pip finds

grape (*Vitis vinifera* L. ssp. *sylvestris* (C.C. Gmel.) Hegi—hereafter *V. sylvestris*—is the wild species, and *Vitis vinifera* L. ssp. *vinifera*—hereafter *V. vinifera*—is the domesticated species). Care needs to be taken to demonstrate how the Indus Civilization fits within discussions of domestication, cultivation and trade of 'grapes' in light of the difficulties relating to morphometric identification of domesticate traits, and of regional taxonomic diversity. In this paper these points are unpacked alongside the published archaeobotanical data for 'grape' at Indus Civilization sites, and the resulting implications for wider Indus agricultural and food use models are considered. The extant data suggests a range of Vitaceae genera could have been exploited by Indus peoples, including several species of *Vitis*. The potential diversity suggested raises important questions relating to trade, agriculture, environmental interactions as well as foodways and taste that could be addressed through better identification of Indus 'grape' remains.

Vitaceae in south Asia and the Indus region

Grapes are part of the family Vitaceae, and were likely domesticated in western Asia and/or south east Europe some time before the third millennium BC (Miller 2008; Zohary et al. 2012; White and Miller 2018; Fuller and Stevens 2019; Pagnoux et al. 2021). The wild ancestor of domesticated grape, *V. sylvestris* is a dioecious form, and as part of the domestication process the genetic shift towards hermaphroditic cultivars permitted self-pollination and thus fixation of desirable traits (Miller 2008; Zohary et al. 2012; Bouby et al. 2013). These traits can then be modified through cutting, layering and grafting.

V. sylvestris has a limited modern distribution, confined to a region that encompasses a band across western Eurasia from the Mediterranean to the Caspian (Zohary and Spiegel-Roy 1975; see also Zohary et al. 2012). It does not stretch into the Indus region. Archaeological evidence has shown that grape was domesticated between the 7th and 4th millennium in the region between the Black Sea, the Aegean and Iran (Châtaignier, 1995; McGovern et al. 1996; McGovern and Rudolph 1996; Zohary 1996; Miller 2008; Terral et al. 2010; White and Miller 2018; Valamoti et al. 2020; Pagnoux et al. 2021; Bouby et al. 2021). Secondary domestications are suggested to have occurred as *V. vinifera* use spread to other regions such as Central Europe and the Near and Middle East (Grassi et al. 2003; Arroyo-García et al. 2006), with changes continuing in grape pip morphology (and grape taste) in Roman France for example (Terral et al. 2010; Bouby et al. 2013). Genetic evidence supports the domestication story shown in archaeological data (This et al. 2001; Aradhya et al. 2003; Lacombe et al. 2004; Snoussi et al. 2004; Ramos-Madrigal et al. 2019). Domesticated grape in Iran by the 4th millennium means that *V. vinifera* presence in Indus sites by the 3rd millennium BC is not outside the realms of possibility. There are however other Vitaceae taxa within South Asia that complicate this simple story.

While many archaeobotanists may be swift to point out that identifying the genus *Vitis* and the species *V. vinifera* in the archaeobotanical assemblage is easy as grape pips have many identifiable features, this is partly due to our training in

Table 1 Periodisation of the Indus Civilization (after Possehl 2002:29). The chronology is still debated, and further work is needed to refine it. The chronology represents a rough periodisation that requires radiocarbon calibration across multiple sites to pin it down further. An alternative chronology can be found in Kenoyer (1998) which also subdivides the Mature Harappan period

Stage	Age (BC)
Painted Grey Ware (PGW) (early Iron Age)	1300–500
Late Harappan	1900–1300
Mature Harappan	2500–1900
Early-Mature Harappan Transition	2600–2500
Early Harappan	3200–2600

regions where *Vitis* is the most important, if not only, genus from the Vitaceae family, and from our use of often heavily Near Eastern or European dominated reference collections.

An examination of the flora for the Indus Civilization region (Pakistan and northwest India – following http://www.tropicos.org/Project/Pakistan, and https://apps.kew.org/herbcat/navigator.do) shows that there are an additional four *Vitis* species beyond *V. vinifera* in the region, and seven genera from the Vitaceae family that have previously been named as *Vitis* sp. (Table 2). This breaks down into 13 species, with an additional four accessions with unresolved taxonomy as denoted by The Plant List (http://www.theplantlist.org/).

This is not to mention the additional eight genera making up 29 species (with two unresolved accessions) of Vitaceae that are not synonyms of *Vitis* sp. found in the relevant flora for the region (Table3).

There is not a vast amount of ecological or biogeographical information on these taxa – many of them have not been studied beyond their accessions in 20th and early 20th century reference collections (https://apps.kew.org/herbcat/navigator.do). Others have limited discussion in relation to medicinal and ethnobotanical studies. For example, *Leea macrophylla* is described as found in the hotter parts of India (Singh et al. 1965), while *Cissus quadrangularis*, a species that has arguably more research into that other Vitaceae taxa in South Asia due to its medicinal value (ESM Table S1) is described by Singh et al. (1965) simply as a common succulent twiner, by Khare (2007) as found throughout the warmer parts of India and grown in gardens, and by Tropicos (http://www.tropicos.org/Project/Pakistan) as distributed across India, Pakistan, Java, East Africa, Malaya, Sri Lanka, Arabia, and cultivated in the gardens of Sind and elsewhere.

Archaeological evidence for Vitaceae in the Indus Civilization

Pokharia and Srivastava (2013, pp 130–131) have noted the presence of grape in their review of Indus Civilization archaeobotanical remains, arguing that pips "suggest that these fruits were in the subsistence economy". Discussions of Indus grapes generally focus on how they are a non-native crop, growing in the region outside its natural wild range, alongside other non-native fruits and nuts such as dates, hackberries, almonds and walnuts (see Fuller and Madella 2002; Pokharia and Srivastava 2013; see also for discussion of domestication and movement Zohary et al. 2012).

In a recent review of the published archaeobotanical literature, 12 sites were noted to have recorded 'grape', *V. vinifera* or *Vitis* sp. remains (Bates 2019b) (Table 4 and ESM). In the majority of these reports the discussions detailed the finds in order to identify them and to describe their importance in relation to other genera at the sites. Strict identification criteria were not always applied

Table 2 List of Vitaceae family plants have previously been named as *Vitis* sp. found in South Asia (based on flora for the Indus Civilization region: Pakistan and northwest India – following http://www.tropicos.org/Project/Pakistan and https://apps.kew.org/herbcat/navigator.do) Taxonomy clarified through The Plant List (http://www.theplantlist.org/)

Taxa	Previous *Vitis* synonym
Ampelopsis glandulosa var. *heterophylla* (Thunb.) Momiy	*V. heterophylla* Thunb
Ampelocissus indica (L.) Planch	*V. indica* L
A. latifolia (Roxb.) Planch	*V. latifolia* Roxb
A. rugosa (Wall.) Planch	*V. rugosa* Wall
Cayratia pedata (Lam.) Gagnep	*V. pedata* (Lam.) Wallich ex Wright
Cissus adnata Roxb	*V. adnata* (Roxb.) Wall
C. paniculata (Balf. f.) Planch	*V. paniculata* Balf. f
Cyphostemma auriculatum (Roxb.) P.Singh & B.V. Shetty	*V. auriculata* (Roxb.) Wall
Tetrastigma obtectum (Wall. ex M.A. Lawson) Planch. ex French	*V.obtecta* Wall. ex M.A. Lawson
Vitis heyneana Roem & Schult	*V. lanata* Roxb
V. flexuosa Thunb	*V. parvifolia* Roxb
V. jacquemontii R. Parker	
V. vinifera L	
Unresolved	*V. glauca* Wall
Unresolved	*V. kleinii* Wall
Unresolved	*V. linnei* [sic *V. linnaei* Wall.]
Unresolved	*V. triloba* Roth

however, and a range of reporting methods can be seen across the 12 sites.

In addition to this summarised quantified data, some reports include interpretive descriptions of the finds (see also ESM). At Mahorana and Rohira it is commented that "on morphological grounds these ancient grape pips indicate their close resemblance with those of cultivated form" (Indian Archaeology, a Review, 1984–1985, p 161). At Nausharo the quantity of pips led Costantini (1990, p 329) to suggest that there is "no doubt as to the importance of such fruits in the human diet" and that "the cultivation of grape vine and the gathering of jujube fruits were already known in the Kachi Plains from the findings at Mehrgarh and certainly *Vitis vinifera* was being cultivated in Pakistan". However, the grape pip descriptions from Mahorana, Rohira and Nausharo are not accompanied by discussions of the flora of the region, reference collections or the morphological/morphometric features that allowed for these identifications to be made.

A more detailed description was provided for the pip at Pirak where Costantini (1979a, p 331; see also Costantini 1981; Costantini and Costantini-Biasini 1985, p 25) describes it as "a small seed, perhaps unripe, laterally deformed by burning. The beak of the seed is short and the chalaza [sic], although not very clear, appears to be elongated in shape and the ventral grooves are divergent". Similarly at Sanghol Saraswat (1997, p 104) describes the pip as "Single pyriform seed […] it has an extended and thick stalk […] Dorsal side shows a circular chalazal scar. Ventral side of the seed is characterised by two deep furrows, forming a solid median ridge. The seed is comparable to those of *Vitis vinifera*." These detailed descriptions were accompanied by photographs at both sites, but no morphometric measurements of the aforementioned features beyond the length, breadth, thickness (L:B:T) at Sanghol. There is also no discussion of the nature of the reference collection material used to create these descriptions or of the regional flora used.

At Shortugai there is perhaps the most in-depth analysis of the pip finds, with a histogram and scatterplot of length:breadth ratios, in order to make an assessment of whether the pips were wild or domesticated types. Willcox (1991, p 149) suggests that "Grape seeds (*Vitis vinifera*) were the most common fruit found and are of a small-seeded variety, only a little larger than wild specimens", based on the histogram and scatterplot (Willcox 1991, Fig. 12.7). However, the underlying primary morphometric data accompanying this figure is not provided, nor are ratios of wild and domesticated seeds growing in the region by which comparisons could be made.

Other analyses have used the environmental setting to interpret the pips as domesticates (*V. vinifera*). The grapes at Mehrgarh "seem to have been introduced into an environment not included in the natural range of the plant" and "the study of the pips found at Mehrgarh has excluded the presence of wild grapes, confirming that grapes were introduced into the area following the development of cultivation techniques elsewhere" (Costantini 1984, p 32). While this discussion outlined the presence of grapes and ascertained their domesticated/wild status, the preservation conditions at Mehrgarh for the grape finds was not outlined in great detail.

A similar environment-led argument is put forwards at Miri Qalat to identify the remains as domesticated *V. vinifera*: the environment would have been unsuitable for wild grape, and thus "we are probably dealing with cultivated species" (Tengberg 1999, p 9). The situation is similar at Shortugai, the most northerly site in the Indus Civilization. The different eco-zone of this site due to its northerly location has led Willcox (1991) to suggest that the presence of grapes and the length:breadth ratios at Shortugai, along with the presence of grapes at other sites in Central Asia and at Loebanr III in the Swat Valley (Masson and Sarianidi 1972; Costantini 1979b, c) could indicate an independent domestication of grape in the area. However, recent genetic analysis and the distribution of wild *V. sylvestris* suggest that this is unlikely. Instead these analyses support the idea that grape domestication occurred in western Asia, in the Southern Caucasus between the Caspian and the Black Sea, with later introgression as grape was moved east and west (see for example Myles et al. 2011; Zohary et al. 2012). A reliance on environmental setting to form the interpretation of remains as specifically *V. vinifera* may therefore be difficult to maintain.

The presence of other proxies at sites has also been used to support discussions about the presence or use by people of *V. vinfera*. At Mehrgarh charcoal fragments of grape vine were found. The authors suggested that this is strong evidence for the cultivation of grape as grape vine is not a good fuel source and grape requires management to encourage good yield, an act that leads to vine pruning (Thiébault 1989, 1992, 1995; see also Miller 2008). At Nindowari grapes was "present as mineralised pips, fruit and wood fragments in the samples from pots" (Costantini 1990, p 329) rather than just as carbonised pips. There is some confusion as to the exact location of the find (see ESM), but the discussion of preservation is important, as it raises questions about how and why 'grape' was brought back to site, processed and used. Experimental work by Cartwright (2003) and Mangafa et al. (2001) shows that *Vitis* sp. fruits when dried (i.e. to make raisins) puff when charred, making them look like grapes again. However, as these finds are mineralised more work would need to be done to confirm this food preservation method in relation to the archaeological preservation and taphonomic pathways.

The presence of both charcoal and whole grapes, assuming these are *V. vinifera*, could be used to argue for Indus viticulture (see Pokharia and Srivastava 2013). Miller (2008) and White and Miller (2018) have argued that the presence of grape pips alone are note enough to argue for grape cultivation, only grape exploitation. The presence of pollen data, wood charcoal, residues, architectural features, material culture and artistic representations have been used in other parts of the world to successfully argue for viticulture, alongside pips, pedicles and skins (see Çizer 2006; Deckers 2010; Riehl 2010; Capper 2012; Miller and Strosahl 2013). The presence of wood charcoal identified to *Vitis* sp. at Mehrgarh (Thiébault 1989), and mineralised remains of whole fruits and *Vitis* sp. wood fragments at Nindowari alongside seeds (Costantini and Costantini-Biasini 1985; Costantini 1990) could thus be argued to represent viticulture in the Indus. However, it also has to be remembered that wood charcoal remains suffer from the same identification challenges as seeds – there are still questions about the species and genus level identifications of Vitaceae wood charcoal and mineralised fruits are notoriously hard to identify to species or even genus level due to lack of well preserved features. What the presence of Vitaceae charcoal and fruits might suggest however is that some form of exploitation beyond casual use was occurring, because as Thiébault (1989, 1992, 1995) suggest Vitaceae is not a good wood fuel source and thus implies pruning or at least clearing of unwanted vines from an area. Whether this amounted to cultivation and viticulture is another matter, and whether this data can be stretched Indus-wide is also debatable.

Taphonomy also needs to be addressed. While there are mineralised fruits at Nindowari these are a unique find (indeed mineralised remains are a rarity in the Indus – see Bates 2019a). Discussion of preservation and taphonomic pathways are rare in the Indus pips. Indeed it is only at Sanghol that an explicit discussion is made: Saraswat (1997, p 104) notes deep cracks from carbonisation had greatly affected his sample. This would necessarily have affected the measurements made on the Sanghol material through distortions, and raises questions about all other measurements on the Indus materials. While grape pips are durable, and likely to survive charring (White and Miller 2018), charring will still affect the features of Vitaceae seeds. Most of the work relating to the taphonomic effects of charring on Vitaceae has, as might be expected, been carried out looking at the length:breadth ratios of *V. vinifera* and *V. sylvestris* to ascertain if charring affects domestic/wild discrimination. Work by Logothetis (1974, 1970), Mangafa and Kotsakis (1996) and Smith and Jones (1990) demonstrated that charring does indeed lead to changes in the overall shape of grape pips, with seeds becoming rounder and smaller overall, changing the ratios traditionally used to make such identifications (see also debates in Negrul 1960; Terpo 1977; Kislev 1988). The use of morphometrics to make identifications even at genus level is extremely problematic, but alongside this as Tiffney and Barghoorn (1976, p 173) also point out: "the effects of shape on other morphological characters occasionally renders taxonomic interpretations difficult" and therefore if changes occur differentially in length and breadth this may alter the relationship between different features, skewing identification potential.

The description of Indus grape pips relies greatly on 1) characteristics such as overall pyriform shape which is shared across the Vitaceae family and does not assign the seed to genus, 2) measurements that are not appropriate even at genus level unless extremely detailed and well referenced across the family, 3) to statements on the identification to genus (and species) level without description to support this, and 4) to previous identifications of *Vitis* sp. in the area. Looking across this data then, although only 12 sites report *Vitis* sp., the range of reporting methods for possible Indus grape remains is disparate, with some sites reporting only presence (e.g. Harappa), others providing in-depth morphometrics (e.g. Shortugai, although the data that accompanies the statistics is not provided in the publications), to others that provide figures and/or descriptive sections on grape remains (e.g. Kunal and Rohira). How the data has been interpreted, where the weight of interpretation has been placed (on the morphometrics, the environment, the presence of other proxies, or simply that these must be grape pips) is also highly variable.

Identification challenges

Vitaceae seeds are likely correctly assigned to family level in the Indus archaeobotanical literature as "morphologically, the family is well delimited and easily recognised" overall (Chen and Manchester 2007, p 1,534), with the "unique seed morphology" as one of the "most useful characters to distinguish Vitaceae from other families" (Chen and Manchester 2007, p 1,534).

Much of the discussion in the literature (for example at Shortugai and Rohira Archaeology and a Review, 1983–1984, 1984–1985; Willcox 1991) has focused on whether the grape finds were domesticated or wild (*V. vinifera* or *V. sylvestris*). As explored above there are no wild *V. sylvestris* species in the region, and thus a local domestication of *V. sylvestris* to *V. vinifera* is unlikely based on the distribution of *V. sylvestris*. Complicating any argument relating to South Asian domestications of *Vitis* sp. are the morphometric data.

Bouby et al. (2013, Fig. 2) and Mangafa and Kotsakis (1996) note that not only are length, thickness and breadth required to evaluate grapes as wild or domesticated but ratios of the length of stalk and placement and size of chalaza to

the rest of the seed are also necessary (see Fig. 2). Terral et al. (2010) carried out a detailed study using EFT (Elliptic Fourier Transform) methods to assess grape domesticated status in their study of cultivars in Europe. Their study demonstrated that only by combining numerous measurement points (64 in total) on both the lateral and dorsal view, along with total seed shape and statistical assessment of the measurement errors, could the overall patterns of wild versus domesticated status be ascertained in the wider assemblage. They determined through this method that a domestication process occurred in the Languedoc region of Southern France during antiquity, likely a secondary domestication following the primary domestication in the Black Sea-Iran region. Charring is unlikely to impact morphometrics, but only when initial compartmentalisation (wild versus domesticated, correct genus level identification) is made (see Bouby et al., 2018).

Within the Indus grape pip material, however, morphometrics are limited to length, breadth and thickness, and images illustrating how and where such measurements were taken, such as what was considered the base and where the breadth of the pip was taken, are lacking in the morphometrics, as is a discussion of chalaza placement and morphometrics for stalks. This makes comparing the Indus pips to the Near Eastern domestication data (as noted already problematic as a comparator dataset for non-Near Eastern material), complex to say the least.

Despite this, it can be noted that there is a range of pip sizes in Indus grapes (Fig. 2, in which the length and breadth data from Balu, Kunal, Sanghol and an additional contemporary South Asian site, Loebanr 3 are added to the data from Shortugai). White and Miller (2018), Miller (2008), Kroll (1999) have argued that we should see two types of grape pip if this represented a domesticated *V. vinifera* assemblage, large pips and smaller underdeveloped pips. Looking at Fig. 2 however, there is no bimodal distribution of sizes appearing in the data.

This might imply then that either there is no evidence for domesticated grapes at Indus sites, that these are wild types; that taphonomic and preservation process have occurred that resulted in the underdeveloped pips not being present on site or collected; or that other Vitaceae may have been exploited by Indus peoples.

As stated, the first seems unlikely given the distribution of wild *V. sylvestris*, but in order to establish the latter two statements – that these are domesticated *V. vinifera* or other Vitaceae taxa two things are required: more morphometric work on these pips and the acknowledgement that there are other possible Vitaceae in the region. While more morphometric analysis is outside the scope of this review, this paper can outline the identification potentials for the other Vitaceae in the region and provide identification features to assess these finds in the future.

While identifications of Vitaceae to family level are likely to be accurate, seed morphological characteristics within the Vitaceae family have not been thoroughly surveyed or explored. Much of the description of Vitaceae dates to earlier works, including Kirchheimer (1957, 1938, 1939), Ladcucka-Srodoniowa (1966), Miki (1956), Schiemann (1953), Stummer (1911). These focused on specific genera, and were thus "limited surveys" (Tiffney and Barghoorn 1976, p 171; Chen and Manchester 2007).

For example, even within the well studied *V. sylvestris* and *V. vinifera*, while there are extensive morphometric datasets available, these morphometric descriptions are specific often to the Near East, Europe, or later historical periods where the domestication status of grape have been well established and transitionary stages are not seen (see discussions on the uses of morphometrics in archaeobotany in Portillo et al. 2020). The EFT method utilised by Terral et al. (2010) relies on the pips being confidently identified to *Vitis* sp., and to a rough identification to either *V. sylvestris* or *V. vinifera* before they can be applied. In regions like South Asia where there are other taxa, this is difficult to apply and the limited surveys become problematic.

As a starting point, Chen and Manchester (2007, p 1,535) provide a comprehensive description of the seeds of Vitaceae. Specifically they note that paired ventral infolds and dorsal chalaza are unique to this family, and that the seeds also have an apical notch, beak on the hilum, median groove on the dorsal side extending from the chalaza either apically or basally (genus dependent).

According to Tiffney and Barghoorn (1976, Table 1, Fig. 1) and Chen and Manchester (2007, Fig. 1) in order to achieve intra-family identifications, specific aspects of these general Vitaceae features need to be explored. Table 5 replicates the features outlined in Tiffney and Barghoorn (1976) that outlines the descriptive features required to explore genus level identification of Vitaceae. These features can be modified to include a more quantified method of comparing seeds, or by gaining data on whether something counts as shallow/deep, by ensuring that measurements are always taken in the same place. To this end, it is suggested that a standardised method for measuring seeds is followed for future Indus Vitaceae finds (Fig. 3), using terminology from Tiffney and Barghoorn (1976, Table 1 and Fig. 1) and Chen and Manchester (2007, Fig. 1) and measurement placement points from Chen and Manchester (2007) and (Bouby et al. 2013, Fig. 2). Further points where measurements can be taken can be seen in Chen and Manchester (2007, Fig. 2).

Work by Chen and Manchester (2011) and Gong (2009) is ongoing to create systematic, statistically significant quantified morphometric models and qualitative descriptive keys of the Vitaceae family that show promise for this kind of analysis. However, given the diversity of the family, the inter and intra species variability a full identification key for

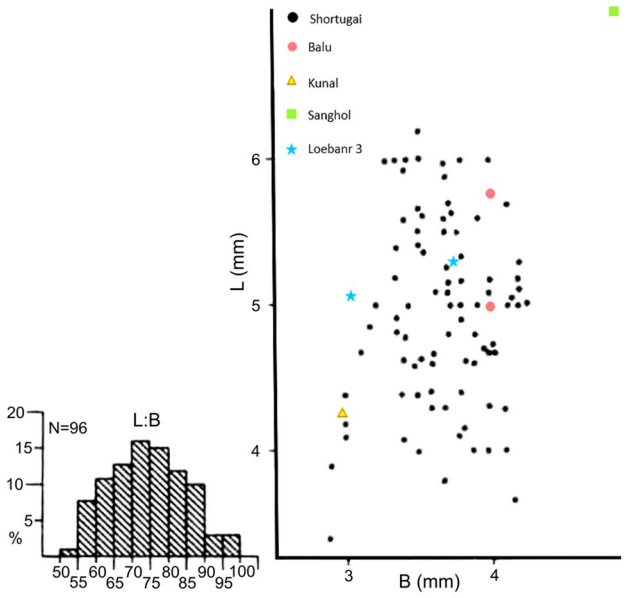

Fig. 2 Measurements of Indus grape pips from published literature placed on scatterplot of measurements from Shortugai. Measurements from Loebanr 3, a contemporary site in the region, added for comparison (Costantini 1987). Modified from Willcox 1991: Fig. 12.7; left: histogram of frequency distribution of length:breadth index of *Vitis* sp. pips; right: scatter diagram of length and breadth measurements of *Vitis* sp. pips

Vitaceae is a long and ongoing task, and many genera and species remain to be explored in a statistically significant and descriptively detailed fashion.

Importantly, it should be noted that while "in general the seeds can be distinguished to at least the generic level by a combination of certain morphological characters […], typically involving shape/position of chalaza and shape/length of ventral infolds" (Chen and Manchester 2007, p 1,535), "the shape and morphology of seeds from the same plant can be influenced to a remarkable degree by the number of seeds per berry" (Tiffney and Barghoorn 1976, p 172). This can result in within-genera difference in shape, e.g. within *Vitis* sp. there are three/four seed forming berries with trigonal seeds and two seed berries with rounded seeds. This has a corresponding effect on "the topographic relations of such characters as the chalaza and the ventral infolds" (Tiffney and Barghoorn 1976, p 173). The resulting take-home message is: "Seed shape alone cannot be used as a definitive characteristic, and the effects of shape on other morphological characters occasionally renders taxonomic interpretations difficult" (Tiffney and Barghoorn 1976, p 173).

Despite these caveats, generic identifications are possible if careful comparisons are made using multiple features beyond simply seed shape and/or size alone. As Chen and Manchester (2007, p 1,535) note: while "there are usually two or three distinct seed morphotypes within nonmonotypic genera; […] the unique feature(s) of a genus are more or less consistent in all morphotypes". They note several key features that can allow genus level distinctions in several Vitaceae species, including the nine genera noted for the region that the Indus Civilization covered (Table 6). Examples of the different Vitaceae morphologies for some of the species that can be found in the Indus region can be seen in Fig. 4, and the diversity that can be seen in *Vitis* sp. beyond *vinifera* and *sylvestris* can be seen in Fig. 5. Using even limited features these features outlined in Chen and Manchester (2007) and summarised in Table 6 suggest that genus level identification can be achieved. This does however require a combination of features to be used, not simply relying on one feature or element alone such as shape or length:breadth measurements.

A (limited) reassessment of the Indus pips

In the Indus 'grape' archaeobotanical identifications, size, the use of limited morphometrics, and shape feature heavily in the descriptions. As noted above from both Chen and Manchester (2007) and Tiffney and Barghoorn (1976), as well as in Miller (2008) and White and Miller (2018), these features are problematic in identifying modern species, let alone when applied archaeologically.

Exploring the Indus reports of grape pips, it can be argued based on the available descriptions and images that it is difficult to assign the genus *Vitis* sp. with a high degree of confidence to the published descriptions and images, let alone to discuss species levels identifications. At Kunal, only images are available alongside the measurements (Saraswat and Pokharia 2003, Plate 71, Fig. 9), and these suggest the identification of *Vitis* sp. may be questioned as the ventral infolds appear to be widely divergent and long, deep and perhaps rounded to a degree. This could imply *Tetrastigma* sp. or maybe *Ampelocissus* sp., but the image is blurred and shows only a dorsal view. Without additional detail it is hard to make a confident judgement, and as such a Vitaceae level re-assessment of identification can be suggested only.

At Nausharo, the image suggests parallel, short and linear ventral infolds, and the chalaza is hard to see from the one dorsal view (Costantini 1990, Fig. 4). These could imply *Vitis* sp. but equally *Leea* sp. or *Cissus* sp. (although the infolds are perhaps not as closely spaced) or *Ampelopsis* sp. Again, clearer images and more description of how the identification was reached is required. At Pirak the image appears to show a lateral view rather than dorsal or ventral (Costantini 1979a, b, c, Plate LVI, Fig. D), but the description notes the seed had "divergent" infolds and an "elongated chalaza" (Costantini 1979a, b, c, p 331), features which do not fit with the *Vitis* sp. genus, and instead could align with *Tetrastigma* sp. or maybe *Ampelocissus* sp. and at Sanghol, the description of the seed outlines a "circular chalazal scar"

Table 3 List of other Vitaceae family plants found in South Asia (based on flora for the Indus Civilization region: Pakistan and northwest India – following http://www.tropicos.org/Project/Pakistan and https://apps.kew.org/herbcat/navigator.do) Taxonomy clarified through The Plant List (http://www.theplantlist.org/)

Genus	Species	Previous name
Ampelocissus	*indica* (L.) Planch	*A. arnottiana* Planch. (also a synonym of *V. indica* L. in the floras)
	divaricata (Wall. ex M.A. Lawson) Planch	
	latifolia (Roxb.) Planch	
	sikkimensis (M.A. Lawson) Planch	
	tormentosa (B. Heyne & Roth) Planch	
Ampelopsis	*glandulosa* (Wall.) Momiy	
	vitifolia (Boiss.) Planch	
Cayratia	*tenuifolia* (Wright & Arn.) Gagnep	
Cissus	*adnata* Roxb	*C. pallida* (Wright & Arn.) Steud (also a synonym of *V. adnata* (Roxb.) Wall. in the floras)
	assamica (M.A. Lawson) Craib	
	heyneana Planch	
	quadrangularis L	*Vitis quadrangularis* (L.) Wall. ex Wright (though not in the relevant floras –listed as *Cissus*)
	spectabilis Hochst. ex Planch	
	trifoliata (L.) L	*C. carnosa* Lam
	vitiginea L	
Cyphostemma	*trilobata* (Lam.) M.R. Almeida	*Cissus trilobata* Lam
Leea	*asiatica* (L.) Ridsdale	*L. edgeworthii* Santapam
	guineensis G. Dom	
	macrophylla Roxb. ex Hornem	
	setuligera C.B. Clarke	
Parthenocissus	*quinquefolia* (L.) Planch	
	semicordata (Wall.) Planch	
	tricuspidata (Siebold & Zucc.) Planch	
Tetrastigma	*affine* (Gagnep. ex Osmaston) Raizada & H.O. Saxena	
	hookeri (M.A. Lawson) Planch	
	lanceolarium (Roxb.) Planch	
	obovatum Gagnep	
	planicuale (Hook. f.) Gagnep	
	rumicispermum (M.A. Lawson) Planch	
unresolved		*Cissus dispersa* (not listed in the Plant List)
unresolved		*Tetrastigma gamblei* B.V. Shetty & P. Singh

consistent with *Vitis* sp. but also *Parthenocissus* sp. Crucially at Sanghol the seeds are described as having "deep furrows [infolds]" (Saraswat 1997, p 104). These align better with *Vitis* sp. than with *Parthenocissus* sp., although again, the images make this hard to clarify.

These limited reassessments based on the available images and descriptions show how variable the pips and information are, and how more work on them is required, utilising the full diversity of South Asian Vitaceae as a baseline, rather than assuming *V. vinifera* (or the more dubious *V. sylvestris*) as the only comparator material.

Implications of *Vitis* sp. and other Vitaceae in the Indus Civilization

There is a long history of grape use in South Asia beyond the Indus Civilization. Historical documents testify to their potentially widespread use dating back to the Early Historic

Table 4 Summary of the published reports of *Vitis* sp. in the Indus Civilization. Further descriptions of the reports can be found in ESM. Morphometric measurements are limited in papers to L (length), B (breadth) and T (thickness) of pips

Site	Period	No. of pips	Morphometrics	Images	References
Balu	Mature Harappan	2	5–5.75 mm (L) 4 mm (B) 2–2.5 mm (T)	Pl. 76, Fig. 9	Saraswat and Pokharia 2002
Harappa	Early, Mature and Late Harappan	'Multiple'			Weber 2003
Kunal	Sub period IC (Early Harappan)	1	4.25 mm (L) 3 mm (B) 3.25 mm (T)	Pl. 71, Fig. 9	Saraswat and Pokharia 2003
Mahorana	Late Harappan c. 2100–1900 BC	'Multiple'			Indian Archaeology, a Review, 1983–1984 1984–1985
Mehrgarh	Period V and cf. IV	'Multiple'			Costantini 1984, 1989, 1990; Jarrige et al. 1995; Thiébault 1989, 1992, 1995
Miri Qalat	Period IIIC c. 3200–2500 BC; Period IV c. 2500–2000 BC	Period IIIC, 1 pip; Period IV, 2 pips			Tengberg 1999
Nausharo		'Multiple'		Figure 4	Costantini 1990
Nindowari		'Multiple'			Costantini 1990; Costantini and Costantini-Biasini 1985
Pirak	Period I c.1600 (Late Harappan)	1		Pl. LVI, Fig. D	Costantini 1979a, 1981; Costantini and Costantini-Biasini 1985
Rohira	Period IA (Early Harappan)	1			Indian Archaeology, a Review, 1983–4; 1984–5
Sanghol	Late Harappan/Baran	1	L: 7 mm (L) B: 5 mm (B) 3.5 mm (T)	Pl. 52, Fig. 21	Saraswat 1997
Shortugai	Early-Mature Harappan Period I, Level 2, Period I-II Mature-Late Harappan Period II, Level 3 and 4 Post-Harappan BMAC Period III, Level 3	Early-Mature Harappan Period I, Level 2, 76 pips; Early-Mature Harappan Period I-II, 29 pips Mature-Late Harappan Period II, Level 3, 16 pips; Level 4, 1 pip post-Harappan/ BMAC Period III, Level 3, 3 pips	Histogram and scatterplot (Fig. 12.7) but no primary morphometric accompanying data		Willcox 1991

Table 5 Terminology for standardised methods for describing seeds (from Tiffney and Barghoorn 1976: Table 2 and Fig. 1 and Chen and Manchester 2007: Fig. 1)

Feature	Descriptors	Appearance
Size	Length/width	
Shape	Overall outline	
Beak	Present/absent	Prominent/reduced
Beak shape	Conical-pointed/cylindrical	
Chalaza shape	Round/elongate/linear/spatulate	Recessed/surficial
Chalaza position	Location on dorsal face	
Chalaza, apex groove	Present/absent	Broad/narrow; deep/shallow
Chalaza, basal groove	Present/absent	Broad/narrow; deep/shallow
Dorsal radiate markings	Present/absent	Deep/shallow
Apical notch	Present/absent	Wide/narrow; deep/shallow
Ventral infolds	Length (relative to whole seed)/width/depth	
Ventral infolds shape	Parallel/diverging/j-shaped	External margins: smooth/rough
Raphe ridge shape	Triangular/linear	Appressed to/raised well above main body of seed
Raphe	Visibility	
Raphe shape	Flattened/thread-like	

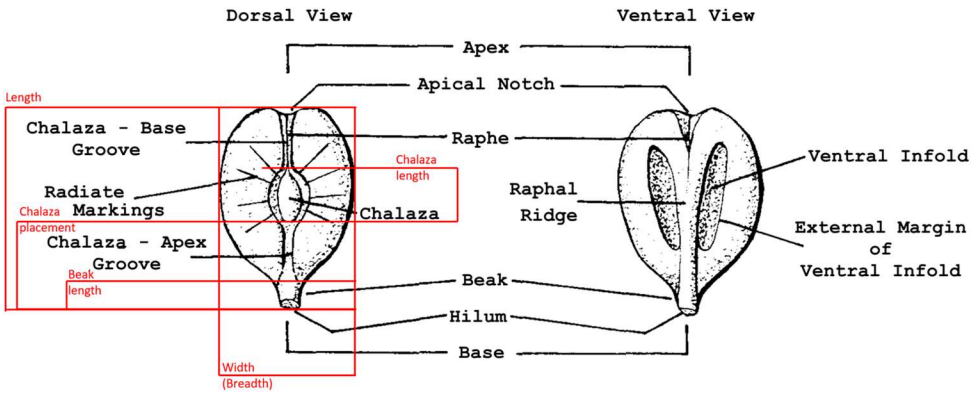

Fig. 3 Measurement placement points for grape pips from Chen and Manchester (2007) and Bouby et al. (2013: Fig. 2). Further points where measurements can be taken can be seen in Chen and Manchester 2007: Fig. 2. Modified from Tiffney and Barghoorn 1976: Fig. 1

period. The Arthashastra, a Sanskrit treatise on statecraft traditionally credited to Chandragupta Maurya's assistant Kautilya but likely the result of multiple authors, records the presence of a liquor translated as 'wine', but also notes that flooded regions are most suitable for the growing of grape vine. This treatise was likely compiled between the second century BC and third century AD (Olivelle 2013). Earlier references to a crop that may have been grape can be found in two other Sanskrit volumes, the Saśruta-Saṃhitā and Charka-Saṃhitā. These early medical texts that form the foundation to the Ayurvedic texts contain references to a plant that has been translated as grape, and to liquids that are translated as grape-wine and grape-juice. For example in the Saśruta-Saṃhitā Chapter VIII grape-wine [Mārdvika] is discussed as part a recipe for improving digestion after treatment for anal fistulas. The Saśruta-Saṃhitā and Charka-Saṃhitā are likely to be the product of multiple authors and redactors who complied multiple texts over many centuries. Although the origin dates are debated, Tipton (2008) places them as dating to between 1000 BC and AD 500. These texts date to much later than the Indus, but show the complexity of the role of 'grapes' in South Asian cuisine and medicine.

The presence of *Vitis* sp. in the Indus Civilization, has however, been predominantly used to argue about the trade in plants or the drift/diffusion of flora packages from the west to the east due to a perceived lack of a wild ancestor for *V. vinifera* in the region. By taking potential Vitaceae diversity in South Asia into account, a new facet can be added to arguments about the complexity of Indus agriculture or food, an aspect that is often missing from the discussions of Indus 'grape' use, or subsumed in the discussions of Indus trade. Exploitation of local *Vitis* sp. or other Vitaceae genera may explain the data as much as diffusion or trade in *V. vinifera,* and more work is needed to clarify the identifications of the pips themselves at all sites.

Many of the lianas of the Vitaceae family respond to pruning and cultivation in positive fashion, producing more shoots and higher yield. Interaction with these plants may

Table 6 Key features that can allow genus level distinctions in the 9 Vitaceae genera noted for the region that the Indus Civilization covered (after Chen and Manchester 2007)

Genus	Ventral infolds					Chalaza	
	Size	Width	Depth	Shape	Ext. margin	Shape	Location on dorsal face
Ampelocissus	Long	Linear	Cup-shaped or dish-like*	Parallel to slightly diverging apically	Irregular to round	Round to oval	Central
Ampelopsis	Short	Linear	Small pit or cup-shaped*	Parallel to slightly diverging apically	Round	Pyriform (cf. spatulate?)*	Near the shallow apical notch
Cayratia	Short		Small pit or cup-shaped, or one large hole on ventral side*	Central	Round	Linear and elongate	Starting from the apical notch of the ventral infolds and central on the dorsal side
Cissus	Short	Linear on surface	Long and linear*	Closely space and parallel		Linear and elongate	Starting from the apical end of the ventral infolds and central on the dorsal side
Cyphostemma	Short	Linear on surface	Covered by extra lignified testa, long and linear*	Closely space and parallel		Linear and elongate	Continuous from ventral side, and central on dorsal side
Leea	Short	Linear on surface	Short and linear*	Closely space and parallel		Linear and elongate	Starting from the apical end of the ventral infolds, and central with extra infolds
Parthenocissus	Long	Linear on surface		Diverging apically	Irregular	Round to oval	Near the deep apical notch
Tetrastigma	Long	Linear on surface	Linear*	Closely spaced and parallel, or divergent in Y or V shape*	Irregular	Linear and elongate	Starting from the apical notch of the ventral infolds and central on the dorsal side
Vitis	Short	Linear on surface	Round, oblong to linear*	Parallel or slightly divergent apically		Round to oval	Central on dorsal side

have been another way for Indus peoples to exploit their locally available resources and extend the diversity of their already extensive agricultural package. While not all of these Vitaceae are necessarily cultivated, those that can be cultivated have divergent ecological or cultivation requirements. Phillips (1991) notes for example the use of swidden, slash-and-burn and nomadic agriculture in Brazil as examples of non-domesticated grape cultivation. Further work is required across the Vitaceae family to explore the biogeography of these genera, and where they will or will not grow. It is notable that the environments of the sites discussed in this paper vary widely – with sites like Shortugai located in the mountainous northern latitudes and others like Rohira, Sanghol, Balu, Kunal and Mahorana in the Indian Summer Monsoonal rainfed plains of the easterly extent of the Indus. These geographic divergences across the Indus are likely to have affected which species could have been exploited (see discussions in Weber et al. 2011a and Petrie and Bates 2017), but further work on the nuances of Vitaceae growing preferences in South Asia are required in order to accomplish this. If further study demonstrates that Indus peoples were exploiting more than one genus of Vitaceae (or even more than one species within *Vitis* sp.) then that again adds a new angle to the already growing picture of Indus agricultural complexity and nuance (Weber et al. 2011a; Petrie and Bates 2017).

This diversity extends to the Vitaceae family more generally. Within the family there are numerous edible and

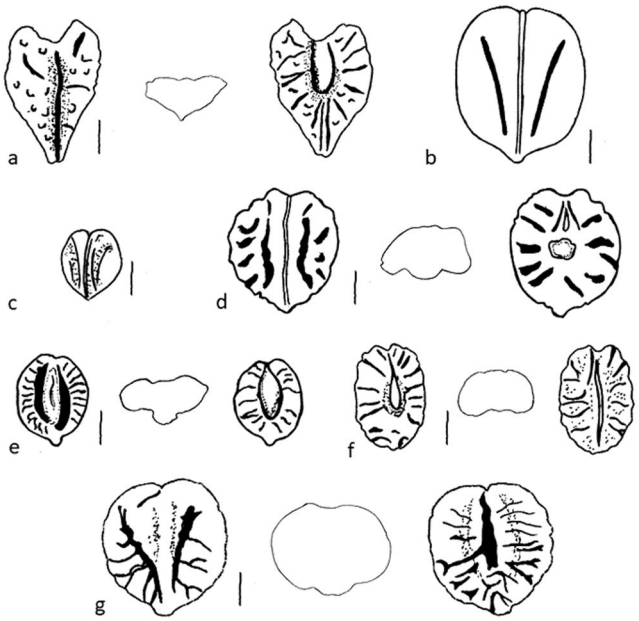

Fig. 4 Examples of Vitaceae seed morphology from taxa that can be found within the study region. **a** *Tetrastigma rumicispermum* (Chen and Manchester 2011: Fig. 10f); **b** *Parthenocissus quinquefolia* (Bricky 1965: Fig. 1f); **c** *P. tricuspidata* (Martín-Gómez et al. 2020: Fig. 8); **d** *Ampelocissus tormentosa* (Chen and Manchester 2007: Fig. S2); **e** *A. latifolia* (Chen and Manchester 2007: Fig. 5d); **f** *Tetrastigma obtectum* (Habib et al. 2018: Fig. 5d); **g** *T. lanceolarium* (Chen and Manchester 2007: Fig. S7h); scale bar 2 mm

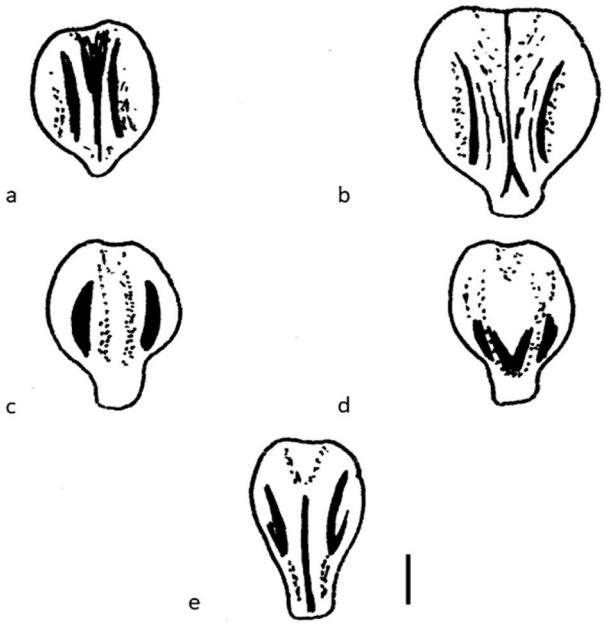

Fig. 5 Examples of *Vitis* sp. morphology diversity. Although these species (beyond the debates surrounding *sylvestris* and *vinifera*) are not found in the Indus region, they demonstrate the problems of assuming that a 'grape' pip is either *sylvestris* or *vinifera* when other species of this genera are present in a region. This would be exacerbated when taphonomy and preservation are taken into account, and other genera of Vitaceae are also considered (Martín-Gómez et al. 2020: Fig. 5), and it can also be noted that in Martín-Gómez et al. (2020) there is morphological consideration of modern *vinifera* variant morphology variation and within variant diversity. **a** *Vitis amurensis*; **b** *V. labrusca*; **c** *V. rupestris*; **d** *V. sylvestris*; **e** *V. vinifera;* scale bar 2 mm

'useable' species beyond *V. vinifera*. Phillips (1991) notes that not only are numerous species used in tropical regions for making wine where *V. vinfera* cannot grow, but may also be used for their raw fruits, for jellies, and for their shoots and eaves in vegetable recipes, all dependant on the characteristics of individual species. Looking across the genera and species that grow in the Indus Civilization region (Table 3), it can be seen that some of the species that could have been exploited by Indus peoples are listed as specifically having edible fruits such as *Tetrastigma lanceolarium* and *Ampelocissus latifolia* (Singh et al. 1965), while others are listed as having edible shoots used in curries (*Cissus quadrangularis* – https://indiabiodiversity.org/). Indeed some have economic value, with *Cissus vitignea* "reported to be edible and sold as wild grapes" in Tamil Nadu (Manokari and Shekhawat 2019, p 81). This detailed level of ethnobotanical information not available for all the genera and species across the Vitaceae family that could have grown in the region, and further work is needed. It can be suggested however, that each genus's fruit will produce flavours depending on sugar and tannin content, and this may affect whether it is selected as a fruit for eating, for wine making, for jellies or for other food use, as will the leaves and shoots.

Beyond food however, the medicinal properties of Vitaceae have a deep history in South Asia and across the world. Phillips (1991, p 465) notes the role of Vitaceae as a medicinal plant: "a strong theme is their use as treatment for swellings, boils, rheumatism, lumbago and headaches". Vitaceae species have been used in Aryuvedic medicine as cures for ulcers and skin complaints (e.g. *Cayratia pedata,* Khare 2007), for bone damage and as a muscle relaxant (e.g. *Cissus quadrangularis,* Khare 2007), as a vermifuge (e.g. *Leea macrophylla,* Singh et al. 1965; Khare 2007) and for stomach complaints including as a cure for diarrhoea (e.g. *Cayratia pedata,* Khare 2007) and as a purgative/digestive (e.g. *Cissus quadrangularis,* Khare 2007). Caution however is needed to compare these much later Vedic uses of Vitaceae with possible Indus uses, and instead an in-depth analysis of taphonomy, preservation pathways and context/assemblage is needed rather than assuming utilitarian function based on 'inherent' or later functionality (Bates 2019a). For example, the fruits, leaves and shoots could also be edible to animals (such as *Cissus quadrangularis,* Merinal and Viji Stella Boi 2012) and thus end up on an Indus site if burned in dung fuel (Lancelotti 2018), and this needs to be incorporated into models through further research into 'grape' uses across South Asia. Making direct links between

modern and historical uses and pre/proto-historic Indus uses of 'grape' is however difficult and must be undertaken with care (Bates 2019a).

If these pips do indeed prove to be *V. vinifera* this provides an interesting avenue for exploration of Indus foodways akin to the work underway by Terral et al. (2010) and Bouby et al. (2013) looking at grape variety development through complex morphometric work in relation to regional secondary domestications. Not all *V. vinifera* grapes today taste the same or have the same use. This is due mainly to selective breeding for new varieties, grafting and cloning until only the traits desired are retained, but it demonstrates the importance of taste and use to humans in their use of grapes. In Pakistan today ten varieties of grape are commonly grown (https://agrinfobank.com.pk/varieties-of-grapes-in-pakistan/), each with different properties. Some relate to maturation time, linked to monsoonal tolerance, others to yield under different soil conditions, but each also has qualities beyond the ecologically deterministic. For example, Narc Black is particularly suited to monsoonal environments and produces good table grapes, Thompson seedless produces grapes suitable for table, sultanas and sultanas for making white wine, while Perlette is much more restricted in its use as a table grape but produces a very sweet, full fruit, and Muscat (or Muscatil) grapes make a variety of fortified wines with a range of flavour palettes.

Exploring the nuance of Vitaceae, their identification and potential uses, can however provide detail on the bigger picture of Indus environments, floral ecologies, agriculture, foodways, plant use and site taphonomy. It will require detailed and careful identification, following regionally specific reference and floras, but the end result will enrich our picture of Indus Civilization agriculture and plant exploitation. The first step must be to re-examine the remains in the context of the local Floras, to report in a systematic and detailed fashion with measurements and images as well as description. This will then allow us to make more interpretive discussions of the potential uses of this diverse family, and create a vibrant model of Indus food, cultivation and environmental interactions.

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